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Semi-Annual Status Report

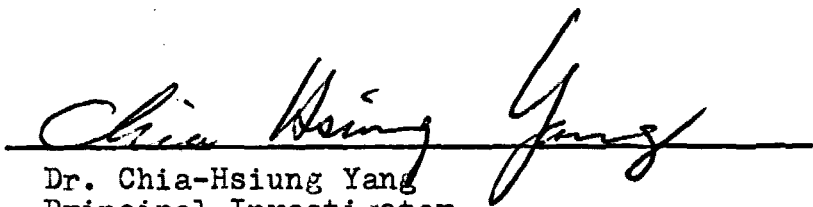
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to Neutron-Star Matter and other Systems"**

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**MANY-PARTICLE THEORY OF NUCLEAR SYSTEM WITH
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Introduction

This will be a brief report on the progress we have made on the following projects during the period of this grant up to this date:

- I. General problems in nuclear -many-body theory
- II. Continuing studies of the superfluid states of of neutron star matter and other strongly interacting many-fermion systems.
 - A. Superfluidity of neutron star matter by using soft-core potential of Reid
 - B. Pion condensation in neutron star matter

I. General Problems in Nuclear-Many-Body Theory

We are investigating certain non-uniform phases of extended nuclear matter and neutron-star matter. These studies have theoretical significance for nuclear-matter theory in general, as well phenomenological implications for the structure of neutron star interiors. Traditionally, calculations of the ground-state properties of non-uniform nuclear systems have been carried out within the frame work of Hartree-Fock, t-matrix, and lowest-order-constrained-variation approaches. After our successful employment of the many-body method of Yang & Clark^{1,2} in the problem of superfluidity of neutron star matter, we are employing the same method to perform explicit calculations including the effects of short-range correlations and at the same time achieve a unified treatment of the various phases.

A trial wave function of the form $\Psi = \prod f(r_{ij}) \Phi$, where Φ is a general model function in the sense of Ref. 3 modified by various interactions when applied is suggested. The Yang-Clark expansion for the energy expectation value E is a cluster expansion in the short-range dynamical correlations induced by the Jastrow factor. Again a "tamed" two-body

interaction

$$w_2(12) = \frac{\hbar^2}{m} (\nabla f(r_{12}))^2 + f^2(r_{12})v(12),$$

is the two-body expression for the potential energy regardless the possibly singular two-nucleon potential in $v(12)$. The YC expansion is cast into a convenient form in terms of the one-, two-, three-, and higher-body density matrices corresponding to Φ , keeping the model function Φ intact in all cluster orders. We are now investigating the possibly calculational, structural, and formal advantages offer by this scheme of calculation.

Our study on the ground state of neutron matter with periodic density variation has been formulated up to two-body order terms. The inclusion of three-body terms and numerical calculation of the problem are now in progress. We are encountering some complications in the three-body term hoping to resolve it soon.

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II. Continuing Studies of the Superfluid States of Neutron Star Matter and other Strongly Interacting Many-Fermion Systems:

A. Superfluidity of Neutron Star Matter by Using Soft-Core Potential of Reid

The formula and numerical calculations for superfluidity of neutron star matter using the soft-core potential of Reid with the two-parameter short range Jastrow correlated function accessible to our method has been completed. They had been reported in the semi-annual report of 1977 and the last annual report. Since then we have found that the two-parameter short-range Jastrow correlated function used in our calculation may not be the best one for the Reid potential (i.e. there are some other correlated functions such as the one used by Pandharipande⁴ that will give a normal state energy close to or even lower than the superfluid state energy got by us using the two-parameter correlated function). Therefore, we want to make some more numerical investigations either by incorporating the three-body terms into our current calculations of normal state energy and the condensation energy or contemplating the same calculations with better short range correlated function.

B. Pion Condensation in Neutron Star Matter

Until several years ago, it was believed that the strongly repulsive s-wave pion-nucleon interaction would prohibit the appearance of free pions in nuclear fluids. If this were the only interaction present it is indeed true that pions would not appear even in neutron-star matter. This is the main reason why we have overlooked the pion condensation in all our studies of neutron star matter up to now⁵. However, it is currently believed that the attractive p-wave pion-nucleon interaction may sufficiently reduce the energy of the pions in the medium so as to make their emergence energetically advantageous^{6,7,8}. Estimates of the critical density at which p-wave attraction is able to overcome the pion energy and s-wave repulsion cover a wide range⁸. Their possible existence in neutron star matter which would effect the macroscopic astrophysical properties of the stars. It also challenges our understanding of nuclear matter at ordinary densities. In view of its possibly great significance to the understanding of the structure of neutron-star problem, we (in cooperation with Dr. J. W. Clark and Mr. David Sandler of Washington University) have started to look into the problem in a self consistent way that employs

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the same many-body method of Yang and Clark^{1,2}. The investigation is now in progress with great prospect for success. I will describe the whole problem in detail in the coming renewal proposal to be submitted in about a month.

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